

THE WORLD OF CHEMISTRY

Program #10

SIGNALS FROM WITHIN

Producer Robert Kaper

Air Script: October 31, 1988

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THE WORLD OF CHEMISTRY

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Annenberg/CPB Project Logo and Music

Funder Credits

MONTAGE: Suntan lotion,
insects, drugs, vegetables,
graphics, models, computer
images

NARRATOR (MUSIC under):
Suntan lotion, insect sex lures, illegal
drugs, chlorophyll and its continuing
miracle of food creation, all molecules
have their own unique arrangements.
They're far too small for us to see
directly. Yet it's possible to make
molecules send out signals revealing
their own internal structure. We can
then determine what atoms the molecules
are made of, and how those atoms are
arranged, by deciphering these signals
from within.

SUPER: SIGNALS FROM
WITHIN

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH in laboratory

ROALD HOFFMANN (SYNC):

The very first question that a chemist asks is, what is it? This may be a sample of moon dust brought back at great expense from the surface of the moon. It might be an impure narcotic off the street, or the extract from the glands of a hundred Gypsy moths. What I want to know is, what are the atoms in these substances, how those atoms are connected up, and what is the shape of the molecule that results. How do we determine the structure of a molecule? Well, we can take a mixture that's impure, because most molecules are impure. We can separate the components. We can purify them. We can put them into the solution. But then what? These molecules, these marvelous little entities, are too small to be seen with any microscope. I ask, speak to me, what are you? Remarkably, they can speak. Molecules can respond to a probe at the molecular level, at their level. That probe is light, or better said, electromagnetic radiation. They interact with that probe. They modify it in a way that depends on their own structure and motions. Here is a molecule in solution. Let's turn off the lights and turn on the laser beam, and what we see is light of a certain color coming out from the laser into the sample, and then coming out, after passing through the sample, of a different color. (cont.)

ROALD HOFFMANN cont:

These imprints of a molecule on electromagnetic radiation, interpreted by us, are the signals from within which tell us what it is that we have.

MONTAGE: Chemists in spectroscopy lab, graphs, sun streaks, jewelry, nature, sunbathers on beach, military night vision scopes, radio tower, x-ray machine, microwave, satellite dish, rainbow

NARRATOR (MUSIC and NAT SOUND under):

Probing matter with electromagnetic radiation is the basis of the analytical technique known as spectroscopy. Any substance can be examined spectroscopically, and many different forms of radiation can be used to analyze it. The key principle underlying spectroscopy is the interaction of the radiation with the material being analyzed. In order to understand the interaction, you have to know something about electromagnetic radiation. Electromagnetic radiation interacts with matter all around us. Visible light interacts with chlorophyll to provide the energy needed for photosynthesis. Radiation that we can't see, ultraviolet, makes skin tan or burn. Infrared radiation lets night vision scopes see objects that otherwise would be invisible. (cont.)

NARRATOR cont:

Radio waves interact with tuning circuits to produce sound. X-rays kill malignant cells. And microwaves cook food.

Electromagnetic radiation makes up a spectrum ranging from high frequencies to low frequencies. The higher the frequency, the more energy the radiation delivers.

GRAPHIC: The visible light spectrum and the electromagnetic spectrum

NARRATOR:

The spectrum of visible light ranges from violet, with the highest frequency, to red with the lowest. So violet packs more energy than red. But visible light makes up only a narrow part of the complete electromagnetic spectrum. Gamma rays have the highest frequency and, therefore, the most energy. X-ray radiation is next, then ultraviolet, visible light, infrared, microwave, and radio.

Shots of people at the pool and on the beach, Coppertone on assembly line

NARRATOR (NAT SOUND under):

How do these different forms of energy interact with matter? One well-known interaction is ultraviolet radiation's effect on skin. Ultraviolet radiation can cause sunburn and skin cancer. (cont.)

NARRATOR cont:

So we have evolved a radiation-absorbing molecule called melanin to protect our skin. Skin exposed to ultraviolet produces more melanin, that is, it tans. Melanin is not the only molecule that absorbs ultraviolet radiation. Chemists have developed artificial molecules for use in suntan lotion. The Schering-Plough Corporation makes Coppertone, and they're continually trying to design more effective molecules to absorb ultraviolet radiation.

Suntan lotion testing

DR. ROBERT SAYRE (VO):

It is a fascinating area of research. What we do with sunscreens is remove the radiation that produces sunburn, skin aging, and skin cancer, and we do this with specific chemicals in these products.

Shot of Dr. Robert Sayre

NARRATOR (NAT SOUND under):

Schering-Plough photobiologist, Dr. Robert Sayre.

INTERVIEW: Dr. Robert
Sayre, photobiologist,
Schering-Plough

SUPER: Robert Sayre

DR. ROBERT SAYRE (SYNC):

We try to select molecules that have the electronic structure that can absorb the radiation, that, that they will settle, they will settle on the surface of your skin, and basically protect you by absorbing the incoming radiation before it can penetrate into the skin.

Suntan lotion testing,
chemist working in lab
with spectroscope,
people on beach

NARRATOR (NAT SOUND under):

Plough tests its products extensively to see how long they stay on in the water, and how well they absorb ultraviolet radiation. The most accurate way to measure ultraviolet absorption is with spectroscopy. A carefully measured amount of sunscreen is first smeared onto a rectangular block made of protein. The protein chemically simulates human skin, and the thin layer represents a typical application of sunscreen on it. The material is then placed in a spectroscope. The device sends ultraviolet radiation through the sunscreen layer and measures how much of it is absorbed by the molecules.

(cont.)

NARRATOR cont:

With this information, Plough scientists can predict how effective those molecules will be in protecting skin. They verify those predictions by exposing human volunteers to simulated solar radiation. The exposure time it took to produce a sunburn is then compared to the time it takes to burn unprotected skin. This comparison lets them calculate the Sunburn Protection Factor, or SPF. An SPF of 2 lets half of the ultraviolet rays through. And SPF of 4 lets only one-fourth come through, and so on.

Sunburn commercial

ACTRESS 1

As the number gets higher the more the damaging rays are being filtered out.
Oh no.

ACTRESS 2

What?

ACTRESS #2

A two!

Shots of people sailing

NARRATOR (NAT SOUND under):

But why do melanin and sunscreen molecules absorb ultraviolet rays? The reason is that any molecule absorbs radiation when it's raised from one energy level to the next, and a molecule's energy levels result from its internal motions.

GRAPHIC: The motion
and energy of molecules

NARRATOR (MUSIC under):

The most obvious form of molecular motion is movement in space from one location to another. So moving molecules possess kinetic energy. But molecules are also involved in internal motions. They rotate, like this two-atom hydrogen chloride molecule. So molecules also possess rotational energy. Another state of energy is vibration. The bonds that hold atoms together are like springs, and molecules vibrate as their bonds stretch and contract. Molecules also possess additional energy from their electrons, which exist at specific energy levels. The larger and more complicated a molecule is, the more energy states it has. Even a relatively simple water molecule possesses energy from bending, stretching, and rotation. All these energies from the different modes of internal motion are discrete, that is, they're at specific levels. Don Showalter.

DS in lab

DON SHOWALTER (SYNC):

Each molecule has only specific sets of energy states, vibrational, rotational, and electronic. Now, in order to get signals from within the molecule, we need to excite it from one allowed energy state to another. Now, that's not quite as simple as it seems. We need to add an exact amount of energy. Now, can we illustrate this idea with, as an example, from our microscopic world. Well, there are a few examples that occur only if we add a specific package of energy, no more, no less. This is an ordinary laboratory beaker. If you hit it, it vibrates with a certain frequency. Now, can we add a specific amount of energy, a package of energy, to this beaker to cause it to vibrate so much that it will break? Let's see.

NARRATOR:

This demonstration uses a sound wave analogy to show that energy must be at the right frequency before it can interact with matter. The only frequency the beaker will absorb is the frequency of the tone it makes when it's hit.

DON SHOWALTER (SYNC):

This is an oscillator amplifier. It produces sound waves. The sound will deliver energy to the beaker. We can also follow the waves and see the waves on the oscilloscope. (cont.)

DON SHOWALTER cont:

The greater the number of waves, the greater the frequency. Now, we want to start with a frequency lower than that of the beaker. Now, let's turn up the volume and see if we can break the beaker. Now, the peaks are getting higher, but their number is still the same. That is, the frequency hasn't changed, it's just got a lot louder. This particular frequency is too low to break the beaker. Let's try a frequency higher than that of the beaker. Still nothing. Now let's try the right frequency, the frequency that matches the beaker's, and we'll turn up the volume full blast, and let's see what happens. The energy directed through the beaker had to be at the right frequency in order for the beaker to vibrate enough to finally shatter. Lower or higher frequencies, even though they were very intense, wouldn't work.

NARRATOR:

On the molecular level, the picture is more complex than the sound wave analogy. Molecules may absorb several different radiation frequencies, depending on their energy levels, and each frequency must provide the exact package of energy needed to lift a molecule from one energy level to the next.

GRAPHIC: Electromagnetic radiation and the change in molecular energy levels

NARRATOR (MUSIC under):

For example, a vibrating hydrogen chloride molecule exists at a specific energy level. A specific package of energy is required to make it vibrate at the next higher energy level.

Electromagnetic radiation at the right frequency will be absorbed by the molecule. It carries just the right package of energy needed to make the molecule vibrate at the next higher energy level. Radiation with a frequency that's too low doesn't carry a large enough package of energy. It can't make the molecule vibrate at the next higher energy level. So it passes through the molecule without being absorbed. And radiation with a frequency that's too high carries too large a package of energy. It's not absorbed either. Its energy is not the specific amount needed to make the molecule vibrate at the next higher level.
Don Showalter.

DS in lab

DON SHOWALTER (SYNC):

Here's a simple spectroscope that works in the visible light region. It has a light source, two focusing lenses, a slit for narrowing down the light beam, a stage for putting a sample on, and a prism.
(cont.)

DON SHOWALTER cont:

And the prism will break up the light into the colors of the spectrum and project it on the screen. Let's first see what the spectrum looks like without a sample in there. I'm gonna turn off the room lights and turn on the spectroscope. The colors we see are the ones we're all familiar with: violet, blue, green, yellow, orange, and red. Now, what would happen if we put a sample in there? The sample that we're going to examine is chlorophyll. I've mixed some grass with alcohol and chopped it up in a blender. The alcohol extracted the chlorophyll from the grass. And look what happens when the light passes through the chlorophyll sample? A band of light is removed. The chlorophyll molecules have absorbed certain frequencies of the visible light. This absorbed energy has lifted some of the electrons in the chlorophyll molecules to a higher energy level. The energy of the absorbed band of light matches exactly the energy difference between the ground state of those electrons and the higher level to which they have been excited.

GRAPHIC: Generalized
spectroscope apparatus
diagram

NARRATOR (MUSIC under):

All spectroscopic instruments have the same basic components, a source of electromagnetic radiation, a container for the sample, and an analyzer detector. The type of radiation used depends on the information we want to get. The sample, whether a solid, liquid, or gas, modifies the radiation passing through it, and the energies emerging from the sample are analyzed and recorded. A graph is produced showing what frequencies have been transmitted and what frequencies have been absorbed.

Shots of illegal drugs,
DEA spectroscopy lab

NARRATOR (NAT SOUND under):

The graph serves as a fingerprint of the substance being analyzed. Drug analysis is one area where spectroscopic fingerprints come in very handy. The many different illegal drugs in circulation require sensitive and precise analyses to identify them. So spectroscopy has become a major weapon in the arsenal of the Federal Drug Enforcement Administration. DEA chemists use infrared spectroscopy, along with other techniques, to analyze drug samples. The first step is to separate the drug from its cutting agent. (cont.)

NARRATOR cont:

The purified drug is pressed into a transparent disc or pellet. The pellet goes into a sample holder, which is placed in the spectrometer.

INTERVIEW: Dr. Ted Kramm, chemist, Drug Enforcement Agency

DR. TED KRAMM (SYNC):

Okay. We're now gonna put the pellet in the spectrometer and do our infrared analysis. We will get a spectrum which will be an unique fingerprint pattern for this particular substance.

DEA spectroscopy lab

NARRATOR (NAT SOUND under):

DEA uses a computerized spectrometer. The computer's memory contains a library of infrared spectra of known drugs. The unknown sample is compared with the information in memory for identification. An infrared spectrum dips down at the frequencies that are absorbed. The location of these dips, or bands, tells what chemical structures are present.

INTERVIEW: Dr. Ted Kramm cont.

DR. TED KRAMM (SYNC):

And then we go to our search button, and we will search our library to see if we have something that will match this spectrum. (cont.)

DR. TED KRAMM cont:

And the search indicates that our compound is most likely cocaine hydrochloride. Now I'd like to show you the difference between the hydrochloride, which is the water-soluble form, and cocaine base, which is also known as free base or crack. Okay. Now, here you can see this this is the hydrochloride. You can see the hydrochloride area right over here, which is absent in the cocaine free base. And the rest of the molecule more or less is similar.

DEA spectroscopy lab,
drug arrests

NARRATOR (MUSIC and NAT
SOUND under):

But what happens when DEA comes across new drugs, ones the computer doesn't have in its library? That was the case when a deadly new drug called China White entered the marketplace. The drug was so powerful that only a tiny amount was needed. And conventional lab tests couldn't detect the minute quantities present in confiscated samples. It was DEA's infrared spectrometers, along with other techniques, that finally broke the drug's chemical code. Dr. Ted Kramm.

INTERVIEW: Dr. Ted
Kramm cont.

DR. TED KRAMM (SYNC):
We found several significant features in the spectrum which helped towards the eventual identification of this compound as alpha-methyl. Now, here's the structure as we had eventually determined, using an assortment of techniques.

DEA spectroscopy lab,
drug arrest

NARRATOR (NAT SOUND under):
With the molecule finally deciphered, DEA chemists were able to develop a test that could be used to identify the drug in the field. Armed with the field test, agents were finally able to arrest the manufacturer as he delivered eight pounds of the drug to a buyer. The test needed to prove him guilty wouldn't have been possible without the DEA chemists and infrared spectroscopy.

Shots of USDA lab work,
cotton plants, computer
models

NARRATOR (MUSIC under):
Infrared spectroscopy's ability to identify known molecules and decipher the structure of new ones makes it useful in many other fields. Scientists at the U.S. Department of Agriculture use it extensively in their research on natural defenses against insects, as a substitute for pesticides. (cont.)

NARRATOR cont:

Infrared spectrometers help them unravel the structures of complex natural molecules to learn how they're put together. Once the structure is fully understood, they try to make synthetic copies of it in the laboratory so it can be mass produced. One important research area is the sex attractants used by female insects to entice males. The sex lures are called pheromones. They offer a safe, nontoxic way to lure insects into traps and avoid the use of pesticides. Dr. Meyer Schwartz makes synthetic insect pheromones in his laboratory.

INTERVIEW: Dr. Meyer Schwartz

SUPER: Meyer Schwartz

DR. MEYER SCHWARTZ (VO/SYNC):

What I am doing here is converting an alcohol to a bromide, which is going to be the starting material for one of our syntheses of a insect sex pheromones. This requires purification, distillation, and verifying the structure by infrared spectroscopy and other means.

Dr. Schwartz working
in lab

NARRATOR (NAT SOUND under):

An important part of Dr. Schwartz's work is confirming that he has made an exact copy of the natural chemical.
(cont.)

NARRATOR cont:

He uses infrared spectroscopy to verify the structure of the molecules he's tried to duplicate in the lab. The spectrometer sends a range of infrared frequencies through the sample, and the spectrum on the screen reveals important characteristics of the molecule's structure.

INTERVIEW: Dr. Meyer
Schwartz cont.

DR. MEYER SCHWARTZ (SYNC):

The ones that are more important at this point are the one here that represents a carbon to oxygen double bond, in combination with this particular band, it represents a acetate ester which, indeed, we were making before.

USDA wind tunnel

NARRATOR (MUSIC and NAT
SOUND under):

Once an accurate copy is made, it's tried out to see if it works. A miniature wind tunnel lets Agriculture Department scientists see just how tantalizing their creation is. The feremone is placed at one end of the tunnel, and a love-struck male Gypsy moth flies against the wind to get it. It's bad enough that he's going to all this trouble for a synthetic chemical, but the Agriculture Department scientists have another dirty trick up their sleeve. (cont.)

NARRATOR cont:

They can control the speed of a striped conveyor belt on the wind tunnel floor. The distracted moth sees the belt moving by and thinks he's flying full tilt toward a female. By carefully adjusting the belt speed, the researchers can stop the moth's forward progress. The speed required to stop the moth gives them a good measure of how strong a sex lure their feremone is. When he finally reaches the end, all he finds are synthetic pheromones in a cold steel cage. Another triumph for chemical ingenuity and spectroscopic analysis.

SUPER: SIGNALS FROM
WITHIN

MONTAGE: Lab demonstration shots, spectrums, program graphics, spectroscopy lab, computer analysis

NARRATOR (MUSIC under):

To review: Electromagnetic radiation interacts with matter. Visible light is only a small part of the full spectrum of electromagnetic radiation. The complete spectrum ranges from gamma rays, through X-rays, ultraviolet, visible light, infrared, microwave, and radio. Molecules absorb radiation when they are moved from one energy level to a higher one. The discrete energy levels of a molecule are the result of its internal motions. (cont.)

NARRATOR cont:

Spectroscopy is an analytical method that makes use of molecular absorption. A beam of radiation is sent through a sample, and a spectrum shows which frequencies have been absorbed and which ones have passed through. The peaks and valleys of the spectrum provide clues to the sample's molecular structure. Spectroscopy is used to identify substances by matching their spectral fingerprints with known spectra and to decipher the structure of previously unknown molecules. Whatever the use, all spectroscopic analysis is based on the same principle, that molecules can produce their own signals from within.

RH in laboratory

ROALD HOFFMANN (SYNC):

What we've seen in this program is spectroscopy mostly used in a fingerprint mode. We have an unknown, and we take a spectrum. That's those peaks, bumps, and valleys in its interaction with electromagnetic radiation, and then we compare that spectrum with the spectra of several known molecules and look for matches. Often the situation is not like that: the molecule that's made in the laboratory was never there before, or it's been isolated from a biological organism for the first time. (cont.)

ROALD HOFFMANN cont:

Still we can use spectroscopy to get a structure. From one spectroscopic technique we get that there is a CH bond and a CO bond. From another technique, we find that this hydrogen is attached to a carbon that has an oxygen, but there are other hydrogens which are attached to carbons that don't have an oxygen. Slowly we piece together the structure of the molecule. There is something interesting about this in that none of these measurements, by itself, proves the entire structure of the molecule. What we get are clues, a partial revelation. What it takes is a chemical detective, the mind of an inquiring, puzzle-solving, man or woman, to piece together from these clues the intricate structure of something like the Gypsy moth feremone.

Credits, Closing Montage, Closing Music

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